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Construction of Permeability Calculation Model of Glutenite in the Northern Steep of DX Sag

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Abstract. In recent years, the glutenite reservoirs are the hot spots of oil and gas exploration. However, the glutenite has various lithologic types, diverse rock components, complex pore structure and strong reservoir heterogeneity, which makes it difficult to accurately calculate the reservoir permeability. Permeability is an important parameter in the later development of reservoir. In order to accurately calculate the permeability of glutenite reservoir, taking the glutenite in the upper fourth member of Shahejie Formation in the northern steep of DX Sag as an example, the lithology and physical properties of the reservoir are analyzed and summarized by comprehensive utilization of logging, core description, scanning electron microscope and other data. On this basis, lithology classification, theoretical derivation and multiple regression methods are used to establish the permeability calculation model of glutenite reservoir, and three types of permeability calculation models are obtained. The advantages and disadvantages of different interpretation models and their causes are compared. The calculation model by theoretical derivation has the highest correlation coefficient (R^2=0.9), but the logarithmic regression formula (R^2=0.88) has better applicability.

1 Introduction

As a kind of oil and gas reservoir with strong capacity of increasing production and storage, glutenite is a research hotspot in recent years. However, it is of complex rock composition, wide particle size distribution, complex pore structure and other strong heterogeneity, so it is difficult to apply logging data to accurately evaluate glutenite reservoirs, and the calculation difficulty of important reservoir parameters such as permeability is greatly increased compared with conventional sand-mudstone profiles. According to porosity and other measurable rock parameters, Phillip H. Nelson[1] classify permeability models into three categories: particle, surface area and pore size. Particle-based models show that permeability is proportional to particle size multiplied by the square of pores. Doyen[2] used rate-controlled porosity method (RCP) to detect pore connectivity and fractal structure, and classified pore size. According to the difference of pore connectivity and its contribution to reservoir permeability, the pores of tight sandstone are divided into nanopores (mainly<0.5μm), micropores (mainly 0.5~1.5μm) and mesopores (mainly>1.5μm). Piper[3] explored the relationship between permeability and diagenetic minerals, and found that the contents of diagenetic kaolinite, calcite and ankerite are inversely proportional to permeability, but permeability is positively correlated with chlorite and siderite.

Permeability determines the effectiveness of reservoir, and has great influence on production and development of reservoir. However, due to the particularity of regional geological conditions, the permeability calculated by common empirical formulas generally does not meet the accuracy requirements. Based on the analysis of the characteristics of glutenite reservoirs, we build three kinds of permeability calculation models of glutenite, which would provide important parameters for exploration and development of glutenite.

2 Reservoir characteristics

Reservoir characteristics are usually characterized by lithology and physical properties. By describing reservoir characteristics, we can have a clear understanding of reservoir space, especially the analysis of permeability.

2.1 Lithologic character

Influenced by sedimentation and tectonics, the lithology types of glutenite in the upper fourth member of Shahejie Formation in the study area are diverse, and the rock composition and pore structure are complex. Based on the core data of key wells in the study area, the rock characteristics of the upper fourth member of Shahejie Formation are analysed.

The reservoir lithology in the area is mainly fine conglomerate, gravelly sandstone and less gravelly sandstone.

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(a) fine conglomerate (b) gravelly sandstone (c) less gravelly sandstone

Figure 1. Lithologic component content.

According to the analysis data of thin rock ore, the main rock components of glutenite in the upper fourth member of Shahejie Formation are quartz, feldspar and rock debris, followed by a small amount of muddy matrix and carbonate cement (Fig.2).

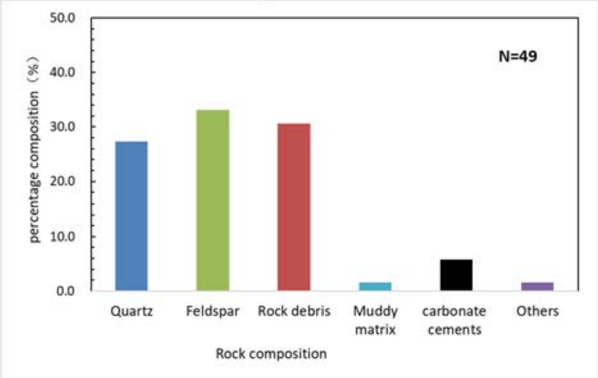


Figure 2. Lithologic component content.

2.2 Reservoir physical property characteristics

Reservoir physical property directly reflects the reservoir permeability and is the most important index to reflect the reservoir properties. Statistical distribution of porosity and permeability of 8 wells in the study area. We find that the porosity of glutenite reservoirs in the study area ranges from 0.9% to 18.8%, with an average of 7.2%, and the permeability ranges from 0.02 to 221.0mD, with an average of 8.19mD, which belongs to low porosity and low permeability reservoirs.

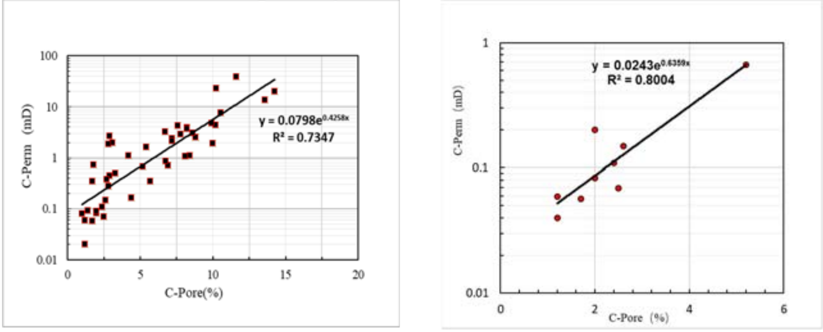
3 Construction of permeability calculation model

3.1 Calculation model by lithology classification

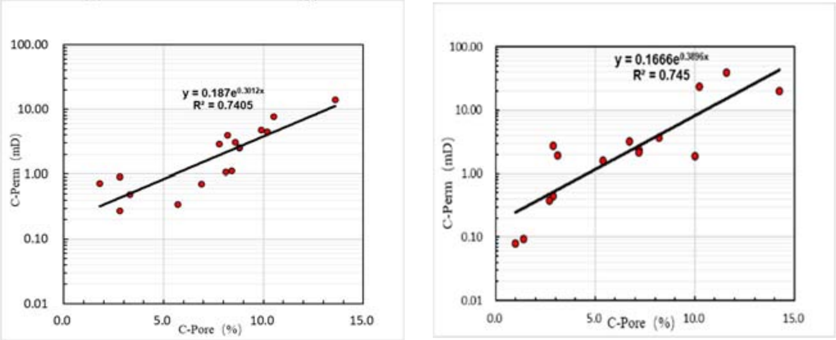
Based on the data of 49 cores in well Y920, the core porosity(C-pore)-permeability(C-perm) intersection of lithologic classification is carried out.

Firstly, the whole porosity-permeability intersection is carried out (Fig.3a), and R^2=0.73.

Then, according to the core analysis data, the C-pore and C-perm intersection of lithology is carried out. The main lithology of the reservoir is fine conglomerate, gravelly sandstone and less gravelly sandstone, and the porosity-permeability intersection diagram of different lithology is as follows:



(a) Unclassified lithology (b) Less gravelly sandstone



(c) Gravelly sandstone (d) Fine conglomerate

Figure 3. The Intersection of C-pore and C-perm.

It can be seen that $R^2=0.80$ for less gravelly sandstone (Fig.3b), $R^2=0.74$ for gravelly sandstone (Fig.3c) and $R^2=0.75$ for fine conglomerate (Fig.3d). Therefore, the fitting formula of porosity-permeability intersection after lithology classification has higher accuracy than that without lithology classification. If these fitting formulas can be applied to the whole well, the accuracy of permeability will be improved. However, the use of these formulas for whole well need the transformation of logging facies and lithofacies, and the transformation requires lithology database from large data base and the use of mathematical algorithms such as cluster analysis, which limits the application of these formulas

3.2 Calculation model by theoretical derivation

According to Ohm's law, the conduction of glutenite with uniform structure can be simplified as the parallel conduction of n "pore-throat". in the equivalent circuit, r_{ma} is the skeleton resistance, and r_i is the ith "pores-throat " resistance. Assuming that L is the length of glutenite, S is the cross-sectional area, and there are n "pore-throat" combinations, L_p and S_p are the length and cross-sectional area of pores, and L_t and S_t are the length and cross-sectional area of throat.

r_i can be expressed as

$$r_i = R_w \frac{L_{pi}}{S_{pi}} + R_w \frac{L_{ti}}{S_{ti}} \qquad i = 1,2,\dots n \tag{1}$$

Where: R_w is the resistivity of formation water, Ω·m.

Expression of resistance r of 100% water-saturated glutenite is:

$$\frac{1}{r} = \frac{1}{R_o \frac{L}{S}} = \frac{1}{r_1} + \frac{1}{r_2} + \cdots + \frac{1}{r_i} = \sum_{i=1}^{n} \frac{1}{r_i} \qquad i = 1,2,\dots n \tag{2}$$

Where: R_o is the resistivity of 100% water-saturated rock.

So, we can get an equation

$$\frac{R_o}{R_w} = \frac{L_p S_t + L_t S_p}{n S_p S_t} \frac{S}{L} \qquad i = 1,2,\dots n \tag{3}$$

According to Hagen-Poiseuille law[4], the flow capacity q per second in a "pore-throat" is

$$q = \frac{\pi r_p^4}{8\mu} \frac{d_{P_p}}{dL_p} = \frac{\pi r_p^4}{8\mu} \frac{\triangle_{P_p}}{L_p} = \frac{\pi r_t^4}{8\mu} \frac{d_{P_t}}{dL_t} = \frac{\pi r_t^4}{8\mu} \frac{\triangle_{P_t}}{L_t} \tag{4}$$

μ is fluid viscosity, Pa·s; $\triangle p_t$ is the pressure difference at both ends of the throat, pa; $\triangle p_p$ is the pressure difference at both ends of the pore, pa; r_p is pore radius, m; r_t is the throat radius, m.

Archie formula[5]

$$\frac{\mathrm{R_o}}{\mathrm{R_w}} = \frac{\mathrm{a}}{\emptyset^{\mathrm{m}}} \tag{5}$$

Based on the simplification of the above formula, the formula of permeability K of rock with uniform structure can be obtained as follows

$$K = \frac{\emptyset^m}{8a} \frac{L_P r_P^2 + L_t r_t^2 \left(\frac{r_P}{r_t}\right)^4}{L_P + L_t \left(\frac{r_P}{r_t}\right)^4} \tag{6}$$

Where: Φ is porosity, decimal; m is cementation index, dimensionless.

For glutenite, the pore radius r_p is larger than the throat radius r_t, and the equivalent length l_p of the pore is smaller than the equivalent length l_t of the throat, so we find:

$$K \propto \frac{\emptyset^m * r_t^2}{a} \tag{7}$$

We tried to make linear regression analysis between permeability and $\emptyset^m * r_t^2$:

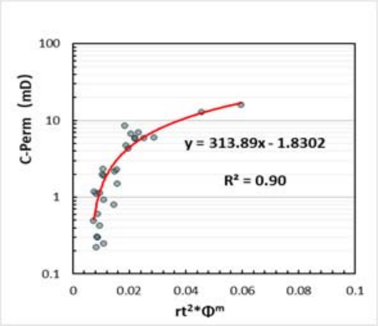


Figure 4. $r_t^2*\Phi^m$ and C-Perm linear fitting.

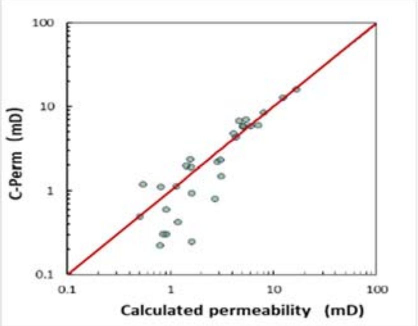


Figure 5. Calculated Permeability and C-Permintersection.

The expression with high R^2(0.90) is

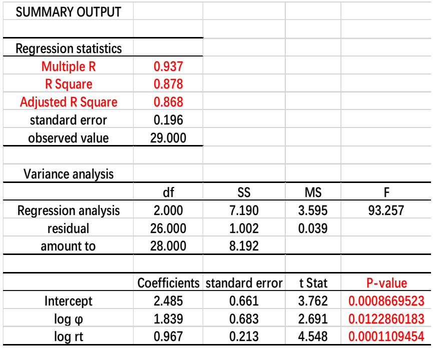
$$K = 313.89 r_t^2 * \emptyset^m - 1.830 \tag{8}$$

Through error analysis (Fig.5), the data below 1mD have large errors, which is probably caused by the complex pore structure of low permeability reservoirs.

3.3 Multivariate linear regression modelling

The formula (8) has a high correlation coefficient when the cementation index m is accurately calculated, but the cementation index can only be accurately obtained by rock electrical experiments, so it is difficult to accurately and continuously calculate by using logging curves. Therefore, we try to remove the cementation index m, and only use the porosity of core data and the average throat radius to fit the core permeability by multiple linear regression, and get a regression formula with relatively high correlation as well as strong practicability.

If multiple regression is carried out directly, the data points below 1mD may be calculated out. Therefore, the data of core permeability, porosity and average throat radius can be processed by logarithm first, then we can carry out multiple regression.



SUMMARY OUTPUT				
Regression statistics				
Multiple R	0.937			
R Square	0.878			
Adjusted R Square	0.868			
standard error	0.196			
observed value	29.000			
Variance analysis				
	df	SS	MS	F
Regression analysis	2.000	7.190	3.595	93.257
residual	26.000	1.002	0.039	
amount to	28.000	8.192		
	Coefficients	standard error	t Stat	P-value
Intercept	2.485	0.661	3.762	0.0008669523
log φ	1.839	0.683	2.691	0.0122860183
log rt	0.967	0.213	4.548	0.0001109454

Figure 6. Logarithmic regression error analysis.

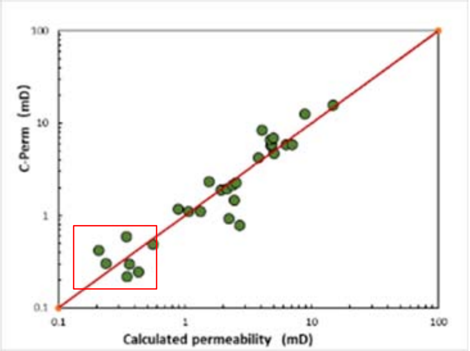


Figure 7. Calculated Permeability and C-Perm intersection.

The fitting formula is

$$\lg K = 1.839\lg\emptyset + 0.967\lg r_t + 2.485 \tag{9}$$

According to Fig.6, R^2 is 0.88. From Fig.7, data are mainly distributed near the 45 line, and the absolute error of data less than 1mD is very small, indicating the accuracy is significantly improved.

4 Conclusion

(1) The reservoir lithology of the upper fourth member of Shahejie Formation is mainly fine conglomerate, gravelly sandstone and less gravelly sandstone, and the rock composition is mainly quartz, feldspar and rock debris, followed by a small amount of muddy matrix and carbonate cement. And the reservoir is of low porosity and low permeability;

(2) For glutenite reservoir, three kinds of permeability calculation models are established by lithology classification, theoretical derivation and multiple regression, among which the theoretical derivation and regression have the highest accuracy, but the formula obtained by logarithmic regression has the best applicability.

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